Environmental Management (2011) 48:1066–1078
DOI 10.1007/s00267-011-9706-4

Major Forest Types and the Evolution of Sustainable Forestry in China

Limin Dai · Yue Wang · Dongkai Su · Li Zhou · Dapao Yu · Bernard J. Lewis · Lin Qi

Received: 23 March 2010 / Accepted: 29 May 2011 / Published online: 16 June 2011

Abstract In this article, we introduce China's major forest types and discuss the historical development of forest management in China, including actions taken over the last decade toward achieving SMF. Major challenges are identified, and a strategy for SFM implementation in China is presented. China's forests consist of a wide variety of types with distinctive distributional patterns shaped by complex topography and multiple climate regimes. How to manage this wide array of forest resources has challenged forest managers and policy-makers since the founding of the country. Excessive exploitation of China's forest resources from the 1950s to the late 1990s contributed to environmental problems and calamities, such as floods, soil erosion, and desertification. At the start of the new millennium, the Chinese government decided to shift its emphasis from timber production towards the achievement of sustainable forest management (SFM). With a series of endeavors such as the implementation of the "Six Key Forestry Projects" and the reform of forest tenure policies, and the adoption of a classification system for China's forests, a beginning has been made at reversing the trend of environmental degradation that occurred throughout the latter half of the last century. At the same time, huge challenges remain to be tackled for the development of forestry in China.

Keywords China's forestry · China's forest types · Sustainable forest management · China's forest resource · Six key forestry programs · Eco-construction

L. Dai · Y. Wang · D. Su · L. Zhou · D. Yu · B. J. Lewis · L. Qi
Institute of Applied Ecology, Chinese Academy of Sciences, Shenyang, Liaoning, China

Y. Wang · L. Qi
Graduate University of Chinese Academy of Sciences, Beijing, China

D. Su (✉)
Jilin Forest Industry Group Limited Liability Company, Changchun, JiLin, China
e-mail: sudongkai1313@gmail.com

Introduction

In 2010, the United Nations Food and Agriculture Organization (FAO) issued a report– the *Global Forest Resources Assessment 2010* (FRA)-based on seven thematic elements of sustainable forest management (SFM). The report concluded that while from a global perspective changes in most variables pertaining to the world's forest resources were relatively small, most regions of the world displayed a mix of positive and negative trends, making it difficult to pinpoint a precise level of global progress towards SFM (FAO 2010). The report also highlighted several negative factors operating against the attainment of SFM: in several regions and countries deforestation and natural loss of forest lands are continuing at an alarming rate; the area of primary forests is decreasing by about 4 million ha per year; the area of forest lands adversely affected by fire, insects and diseases is increasing in some regions; employment in forest establishment, management and use is declining globally; and the value of wood removals has been falling sharply.

The FRA report comes at a time when China is emerging from centuries of relative isolation from the rest of the world as it assumes a prominent position in the global economic order. This has been accompanied by profound changes in Chinese society, with concurrent and often severe consequences for the health of the country's

natural environment, including its forest resources. Today as the country is undergoing a period of transformation in its thinking towards forestry and forest management—shifting from a strict commodity focus towards sustainable forestry—it is experiencing many of the problems described above in the FRA report. Excessive exploitation of forest resources over the past five decades has contributed to a variety of environmental problems and calamities including floods, soil erosion, sand storms and desertification.

Facing such serious ecological problems at the start of a new century, the Chinese government has shifted its emphasis from a narrow focus on timber production towards the attainment of SFM. In the last ten years, with the adoption of a set of key national forestry projects, the acceleration of large-scale afforestation efforts, improvements in the conservation of forest resources and a new direction for forest management policies to encourage sustainability, forestry has made significant progress in enhancing the growth of country's forest resources and bolstering the supply capacity of its forests. From 2003 to 2008, forest coverage in China increased by 2.15% and growing stock volume rose by 1.27 billion m^3. Large areas of natural forests are now under effective protection, and the area of plantations (artificial forests) has increased to 61.69 million ha or 38% of the world's total. In 2009, the Chinese government declared a set of ambitious objectives for medium- and long-term forestry development: by 2020, forest coverage in the country will increase to more than 23%, key ecological issues will be effectively addressed, and the country's ecological health will be significantly improved. The goal for 2050 is for forest coverage to exceed 26%, ecological conditions to be stabilized, and a robust forest ecological system and a mature forest industrial system will be established (SFA 2009). This provides both an unprecedented opportunity and an enormous challenge for the development of forestry in China.

In this paper we identify China's major forest types and their distribution and discuss the current forest resource condition and the historical development of forest management in China, including actions undertaken in implementing SMF. We discuss major challenges as well as a strategy for SFM implementation in China.

A Snapshot of China's Forest Resources

China is situated within six climatic zones (Fig. 1) supporting vegetation ranging from tropical forests in the south to boreal forests in the north, and from wetlands along the eastern coast to grassland/desert in the far west. China's forests display distinctive distributional patterns shaped by complex topography and multiple climate regimes, resulting in an uneven distribution across the country. The majority of forests are found in the northeastern and southern parts of China and in the southeastern periphery of the Tibetan Plateau, with a few forested areas scattered in the higher mountains and along the rivers in the desert area of the western part of China (Ni and others 2001). With a few exceptions, China contains almost all of the main forest vegetation types (biomes) of the northern hemisphere. These forests provide a wide range of values and services to the Chinese populace.

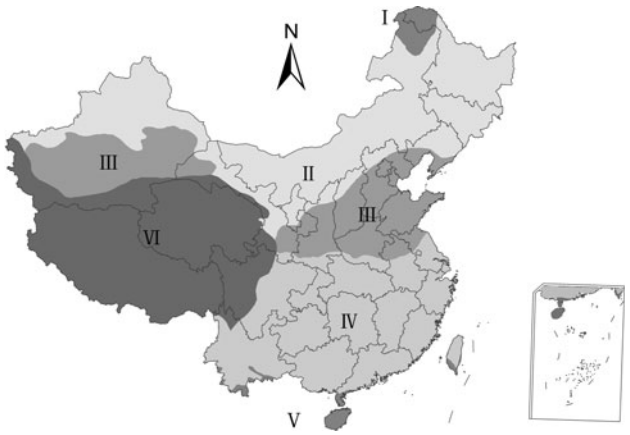

Fig. 1 Climate zones of China (*Source*: Committee for Natural Regionalization of the Chinese Academy of Sciences 1959). I: Cold-temperate zone; II: Mid- temperate zone; III: Warm-temperate Zone; IV: Subtropical zone; V: Tropical zone; VI: Plateau climate zone

Table 1 Major results of National Forest Inventories (NFI) in China

NFI period	Forest area (million ha)	Forest stocking volume (billion m^3)	Forest coverage (%)
1st NFI (1973–1976)	121.86	8.66	12.7
2nd NFI (1977–1981)	115.28	9.03	12
3rd NFI (1984–1988)	124.65	9.14	12.98
4th NFI (1989–1993)	133.70	10.14	13.92
5th NFI (1994–1998)	158.94	11.27	16.55
6th NFI (1999–2003)	174.91	12.46	18.21
7th NFI (2004–2008)	195.45	13.72	20.36

Source: The 7th national forest inventory

Seven National Forest Inventories (NFIs) have been conducted in China (Table 1). The 7th NFI (SFA 2009) revealed that 195.45 million ha of forests cover 20.36% of the country's land area, with a growing stock volume of 13.72 billion m^3. On a country basis this is the fifth largest forest area in the world. Control or ownership of forest lands in China by nongovernment groups or organizations is equivalent to use-rights, since all land ultimately belongs to the central government. With this in mind, the ownership breakdown for China's forest lands as of 2008 was 39.38%

state-owned, 32.08% collectively-owned and 21.73% privately-owned. The area of natural forests (i.e., primary forests that have never been harvested or secondary forests that have been allowed to regenerate naturally at times supplemented with some planting) is 119.69 million ha, which accounts for 61.24% of forest in China. Plantations account for 61.69 million ha or 38.76% of forest in China.

The total carbon stored by forest vegetation in China in 2008 was 7.81 billion tons (SFA 2009). The annual amount of water conserved by forest ecosystems in the country at that time was 494.77 billion m^3; annual soil conserved amounted to l 7.04 billion tons; while annual soil fertilizer conserved totaled 364 million tons. China's forests absorbed 32 million tons of atmospheric pollutants in 2008; while airborne dust absorbed by forests amounted to 5.0 billion tons (SFA 2009). According to the 7th NFI, from 2004 to 2008 the net annual growth in forest growing stock volume was 572 million m^3, while drain from timber harvest totaled 379 million m^3 per year, 39.5% of which came from plantations.

China's Major Forest Types

Based on the characteristics of dominant species, diagnostic species, physiognomy and structure, geographical distribution and ecological environment China's forests may be divided into 8 distinct forest biomes, which together include 23 major forest types (Table 2) (Editorial Committee for Vegetation of China 1980, 2007; Liang 1990; Richardson 1990; Chen and others 1997; Xiao and others 2002; Bystriakova and others 2003). Brief descriptions of each forest biome and its component forest types follow are presented below.

Cold-Temperate and Temperate Mountain Coniferous Forest

This biome accounts for the largest forest area in cold-temperate and altitudinal temperate zones, with a distribution in China that can extend to 53.5° N and altitudes of up to 4300 m. With its rich forest resources, this biome is a major source of wood production in China. It is dominated by tree species of three genera—*Larix*, *Abies* and *Picea*—and includes three major forest types. The first—the deciduous coniferous (*Larix*) forest—is distributed in the far northeast and northwest regions of China and scattered in the mountainous area of central China. The second—the boreal and subalpine *Abies-Picea* forest—is distributed mainly in the high mountains of northeast and northwest China and southeastern Tibet. The third—the *Pinus sylvestris* var. *mongolica* forest—is distributed in Inner Mongolia and far northeastern China. This variety of *P. sylvestris* is an important sand-fixation species capable of taking root in sandbanks and in mountainous areas with poorly drained soils. It can reach a height of 30 m and resists temperatures as low as −40 to −50°C.

Temperate Coniferous Forest

This biome is distributed across the plains, hills and low mountains in the temperate zones of China. It is dominated by tree species of the genera *Pinus* and *Platycladus* and includes two major forest types. The first—the *Pinus tabulaeformis* forest—occurs only in China, where it is a typical type of temperate coniferous forests. It is found primarily in the mountains of north China, extending as far north as the Daqing Mountains of Inner Mongolia. Much of this forest type today consists of secondary or planted forests. Old growth can only be found around temples and as protected areas on the face of famous mountains. The second type—the *Platycladus orientalis* forest—is widely distributed in the mountains, hills and plains of northern China. For this type as well the area of natural forests has been severely reduced; most areas remaining today have been planted.

Subtropical Coniferous Forest

This biome is widely distributed in the subtropical climatic zone of China and is characterized by an abundant array of species, many of which are found only in China. The biome consists mainly of tree species from three families—Pinaceae, Taxodiaceae, and Podocarpaceae—and includes six major forest types. The first—the *Pinus massoniana* forest—is widely distributed in southeastern China, and is the most abundant forest type in the region. It thrives in the central subtropical region, between 600 and 800 m altitude, where height growth can reach 1 m per year and diameter growth 1 cm per year. The *Cunninghamia lanceolata* forest and the *Cupressus funebris* forest are widely distributed in the eastern and central parts of the subtropical zone. They constitute the two major timber-producing forests in south China. The fourth forest type—the *Pinus yunnanensis* forest—is a common coniferous type on the Yungui altiplano in southwestern China, and it is also a representative type in areas of the subtropical zone subject to periodic drought. The fifth type—the *Pinus taiwanensis* forest—is abundant in the eastern mountainous region of the subtropical zone. Finally, the *Pinus armandii* forest is distributed primarily in the mountainous areas of the western subtropical zone. It is valued highly as a timber species.

Mixed Coniferous and Broad-Leaved Forest

This biome is distributed only in the mountains in the northeast and south of China and includes two forest types:

Table 2 Major forest types in China (after Ni and others 2001)

Forest biomes and types	Latitude (°)	Longitude (°)	Elevation (m)	Dominant Species
1. Cold-temperate & temperate mountain coniferous forest				
Deciduous coniferous (*Larix*) forest	42.5–53.5		450–2900	*Larix gmelinii, L. olgensis, L. sibirica, L. parviflora*
Boreal and subalpine *Abies-Picea* forest	22.5–54		1100–4300	*Abies nephrolepis, Picea jezoensis, P koraiensis*
Pinus sylvestris var. *mongolica* forest	46.67–54	112–125	300–900	*Pinus sylvestris* var. *mongolica*
2. Temperate coniferous forest				
Pinus tabulaeformis forest	31–43.55	103.3–124.8	1200–1800	*Pinus tabulaeformis*
Platycladus orientalis forest	34–44		200–1450	*Platycladus orientalis*
3. Subtropical coniferous forest				
Pinus massoniana forest	20–34	100–124	<1000	*Pinus massoniana*
Pinus yunnanensis forest	23–29	93.5–106.5	1500–2800	*Pinus yunnanensis*
Pinus taiwanensis forest	28–33	93–104	600–1750	*Pinus taiwanensis*
Pinus armandii forest	23.5–36.5	88–113	1000–3000	*Pinus armandii*
Cunninghamia lanceolata forest	23–34	98–120	<2000	*Cunninghamia lanceolata*
Cupressus forest	26–30	105–120	300–1200	*Cupressus funebris, C. duclouxan, C. didantea*
4. Mixed coniferous and broad-leaved forest				
Temperate mixed coniferous broad-leaved deciduous forest	40.75–50.3	124.75–134	300–1200	*Pinus koraiensis, Tilia, Betula, Acer*
Subtropical mixed coniferous, broad-leaved evergreen and deciduous forest	24–29.3	109–118	1800–3200	*Tsuga chinensis, T. dumosa, Pinus armandii*
5. Temperate deciduous broad-leaved forest				
Typical temperate deciduous broad-leaved Forest	34–42		<1500	*Quercus, Tilia, Carpinus, Alnus, Ulmus, Acer*
Temperate deciduous broad-leaved shaw	35–42		300–900	
Montane *Populus-Betula* forest	>35		300–2500	*Populus, Betula*
6. Subtropical evergreen broad-leaved forest				
Typical subtropical evergreen broad-leaved forest	23.67–32	99–123	200–2800	*Cyclobalanopsis, Lithocarpus, Castanopsis, Machilus*
Subtropical mixed evergreen-deciduous broad-leaved forest	23–34		<1800	*Quercus, Castanopsis, Cyclobalanopsis*
Subtropical sclerophyllous evergreen broad-leaved forest	26–32	90–103	2600–4000	*Quercus*
7. Tropical rain forest and monsoon forest				
Tropical monsoon rain forest	19–24.6	97.7–109.5	<500–600	*Vatica, Ficus, Antiaris, Aphanamixis, Terminalia*
Tropical rain forest	18.7–22.4	108.8–110.3	<500–1000	*Vatica, Hopea, Dipterocarpus*
8. Bamboo forest				
Subtropical bamboo forest	25–30	98–124	<2000	*Phyllostachys*
Tropical bamboo forest	20–25	97–120	<1200	*Phyllostachys makinoi, Sinocalamus affinis*

temperate mixed coniferous broad-leaved deciduous forest and subtropical mixed coniferous, broad-leaved evergreen and deciduous forest. Both are transitional forest types from mountain broad-leaved forests to mountain coniferous forests. The former type is found near Russia and Korea and is similar with respect to genera of northern Europe and North America, while much richer in number of species. The second forest type is distributed mainly in the mountains of southwest China and central Taiwan.

Temperate Deciduous Broad-Leaved Forest

This biome is distributed in the warm temperate zone and the southern part of the mid-temperate zone of China.

Three forest types are most prominent. The first—the typical temperate deciduous broad-leaved forest—includes three representative forests: the *Quercus mongolica* forest, which is distributed mostly in the northeast and extreme northern parts of China; the *Q. liaotungensis* forest, which occurs in the western area of northeast China and in extreme northern China; and the *Q. acutissima* forest, found in the southern part of north China. The second forest type—the temperate deciduous broad-leaved shaw—is distributed mostly in the northeastern part of China and is comprised of a variety of deciduous broad-leaved species. The third type—the montane *Populus-Betula* forest—is widely distributed in the mountainous regions of the warm temperate and mid-temperate zones of China.

Subtropical Evergreen Broad-Leaved Forest

This is the most widely distributed and representative biome in the subtropical climatic zone of China. It includes three major forest types. The first—the typical subtropical evergreen broad-leaved forest—is distributed in the middle and lower mountainous areas of the central subtropical zone. The second type—the subtropical mixed evergreen-deciduous broad-leaved forest—is prevalent in the northern part of the subtropical zone. There it functions as a transition type from the deciduous broad-leaved forest of the warm temperate zone to the evergreen broad-leaved forest of the central subtropical zone. The third forest type—the subtropical sclerophyllous evergreen broad-leaved forest—is endemnic to the southeastern edge of the Tibetan Plateau and the Hengduan Mountains in the western and southwestern parts of the subtropical zone.

Tropical Rain Forest/Monsoon Forest

Two forest types, distinguished by rainfall patterns, are found in this tropical zone. The first—the tropical rain forest—is limited in area and displays a fragmented distribution across the southern part of Guangxi, Taiwan and Yunnan Provinces, the valleys of southeastern Tibet and Hainan Province, and some small islands in the South China Sea. The second type—the tropical monsoon rain forest—occurs in those areas with distinctive dry and wet seasons, which include the tropical areas of Guangdong, Guangxi, Yunnan, and Taiwan provinces.

Bamboo Forest

Bamboo is an integral part of the world's tropical and subtropical forests. China has the largest national complement of bamboo species—over 500 species within 37 genera—accounting for 36% and 39% of the world total, respectively. While the bamboo forest is widely distributed in China, it is found most extensively in the hills, mountains, valleys and plains in the southern part of the Yangtze River drainage basin with an elevation of between 50 and 800 m. Bamboo forests in China may be classified into two major forest types: subtropical bamboo forest and tropical bamboo forest. The former is distributed mainly in the mountains and plains of the subtropical zone and the latter is distributed primarily in the hills, mountains and valleys of the tropical zone.

Historical Development of Forest Management in China

Based on the nature and sophistication of policies and guidelines, the evolution of forest management in China since 1950 can be divided into three phases.

Phase 1: Discontinuities in Forest Management (Early 1950s to Late 1970s)

Driven by economic and political forces, the forest policies during the first three decades of the country were erratic and disjointed, resulting in an inconsistent pathway for forest management. In 1958, the Chinese government established a forest management guideline which emphasized the need for protecting the mountains, energetic afforestation efforts, and rational timber harvesting. The guideline was later modified in 1964 to promote the idea of the managed forest as one in which logging is combined with improvement cuttings and multi-purpose management. For a decade starting in the mid-1950s, the government pursued a forest policy characterized by tree planting on barren lands and timber harvesting in major forest regions. For a brief time at the end of this period, large-scale tree planting of wastelands began throughout much of the country. Despite these formal policies, however, throughout this period the de facto goal of forestry in China was to produce timber, and excessive harvesting of timber was encouraged (Zhang 2008).

The Cultural Revolution (1966–1976) catapulted China into an unprecedented period of political upheaval and social unrest to the extent that most forestry programs were abandoned, while rampant timber cutting and highly inefficient afforestation campaigns continued (Wang and others 2004). During this period timber harvesting was carried out by forest industry enterprises owned by local governments. With no harvesting limits in place, large areas of mostly natural forests were clearcut, with little priority given to regeneration (Li 2004). At the same time, conversion of forestland to cultivated lands increased and ecological values of forestlands were not taken into consideration (Dai and others 2009). As a consequence, while

more than one billion m^3 of timber was supplied nationwide during this period, achievements in tree-planting were dismal: out of a total of 104 million ha planted during this time, the rate of success was a mere 20% (Wang and others 2004). The 2nd NFI (1977–1981) showed that forest area had decreased 5.4% from the previous inventory (1973–1976). Although overall forest volume had increased 4.3% since that time, both the area and volume of maturing, mature and post-mature forests had decreased sharply from levels at the time of the 1st NFI.

Phase 2: Formal Legal and Jurisdictional Framework with Continued Extensive Harvesting (End of 1970s to Late 1990s)

This phase occurred in conjunction with profound changes in the Chinese economy and society as reflected in national economic reforms, the opening-up of international relations, and rapid development in many fields. In 1984, the country's first forest law—the *Forest Law of the Peoples Republic of China*—was passed, and it officially took effect on January 1, 1985 (Central Government of PR China 1985). The law explicitly stipulated that forestry development be pursued under a policy of general forest protection. It also strongly affirmed the importance of afforestation and linked timber harvesting and sustainable exploitation to afforestation as the basis for management. While declaring that the state encouraged scientific research in forestry, the law also promoted the development and use of advanced technology in upgrading the scientific and technical levels of forestry. Based on the principle that the rate of consumption should be less than the rate of growth, the state was accorded strict control over the annual rate of timber harvesting and authorized to impose annual quotas for timber cutting. Quotas would be set by state-owned forestry enterprises and institutions: for state-owned forests quotas would apply to farms, factories and mines as harvesting units. For collective- and individually-owned forests, quotas would be set for individual counties. Harvesting totals would be collected and consolidated by departments of forestry in the provinces, autonomous regions and municipalities directly under the Central Government and, after examination and verification by people's governments at these levels, submitted to the State Council (i.e., central government) for approval.

From this point in the mid-1980s, the formal direction of forest management in China shifted from entirely unregulated wood production to a harvesting quota system. At the same time, some additional forest programs were (or had been) launched, including the Three-North Shelterbelt Program created in 1978, whose aim was to build a shelterbelt system stretching some 4500 km across North China—and the Afforestation of Taihang Mountains Program, created in 1986, which was adopted to promote the rural economy and protect the natural environment around Beijing and Tianjin. As a result, both forest area and volume increased during this phase. According to the 2nd NFI (1977–1981) and 5th NFI (1994–1998), in 1998, forests covered 16.55% of the land area in China, an increase of 34.1% from 1981. Both area and volume in all age classes—young, maturing, mature, and post-mature forests—increased during this period.

Despite these programs and the legal and jurisdictional measures adopted during this phase of forest management in modern China, most of the state forest enterprises exceeded their timber harvest quotas to increase profits. This was fueled by the increased demand for forest products in China to supply the accelerating pace of economic development. As a result, timber harvests increased from 47 million m^3/year in the 1970s to 63 million m^3/year in the 1990s (SFA 1997; Zhang and others 2000). Moreover, the central government was simply not able to effectively monitor its harvest quotas or reforestation policies, mainly due to the vast size of many state-administered primary and secondary forests and plantations. Thus extensive cutting of forests was inevitable, which led to the disappearance of larger area of primary forest such as deciduous coniferous forest and temperate mixed coniferous broad-leaved deciduous forest in the Northeast. By the latter part of the 1990's most state-owned forest enterprises had run out of timber resources and were facing severe economic difficulties.

Phase 3: Moving Towards Sustainable Forest Management (1998 to Present)

By the end of the 20th century, five decades of excessive forest exploitation had led to severe ecological and environmental degradation across China, as reflected in increased soil erosion, sand storms and desertification, and flooding. Regarding the latter, the huge floods of 1998 in the Yangtze River basin and in the northeastern parts of the country resulted in the loss of several thousand lives and hundreds of thousands of people being left homeless. Faced with such serious environmental problems, the Chinese government decided to shift direction to encourage ecological sustainability while balancing land uses, economic growth, and the demand for forest products.

On April 29, 1998, the National People's Congress passed the *Revision of the Forest Law*, which officially became effective on July 1, 1998 (Central Government of PR China 1998). The Revision identified *ecological/environmental construction* as an important policy objective. This is an umbrella term used extensively in China (and

Table 3 China's six major state forestry development programs

Program	Time Frame[a]	Scope of program	Objective	Afforestation (million ha)[b]	Investment[b] (billion RMB)
NFPP	1998–2010	The upper reach of the Yangtze River; the middle and upper reaches of the Yellow River; Northeast and Inner Mongolia, including 734 counties and 163 forest enterprises	Ensure 94.2 million ha of forest are under effective protection; reduce timber production by 19.9 million m^3; afforest 8.67 million ha	5.35	75.47
CCFP	1999–2010	1897 counties—97% of national total	Convert 14.67 million ha farmland into forests; afforest 17.33 million ha of barren lands and mountains	21.15	153.77
TNSD	1998–2010	596 counties in 13 provinces in north, northeast, and northwest China	Afforest 9.5 million ha shelterbelt	10.80	27.15
SCBT	1998–2010	75 counties in the vicinity of Beijing and Tianjin with land area of 458 thousand ha	Control 10.12 million ha of sand-affected areas; increase forest/grass areas by 5.21 million ha	4.33	23.48
WCNR	2001–2050	Nationwide	Increase number of nature reserves to near 2500, with a total area of 172.8 million ha or 18% of the total land area in China	–	4.13
FGHY	1998–2015	1000 counties in 18 provinces in eastern, central and southern China	Afforesting 13.33 million ha of fast-growing and high-yielding timber plantations	0.94	2.59
	Total			42.56	286.58

NFPP Natural Forest Protection Program, *CCFP* Conversion of Cropland to Forest Program, *TNSD* Three-North Shelterbelt Development Program and the Shelterbelt Development Program along the Yangtze River Basin, *SCBT*S Sand Control Programs for Areas in the Vicinity of Beijing and Tianjin; *WCNR* Wildlife Conservation Nature Reserves Development Program, *FGHY* Fast-Growing and High-Yielding Timber Plantations

[a] Includes 2–3 year trial period; the NFPP was formally adopted in 2000 and the other five programs were all formally adopted in 2001

[b] From 1998 to 2008

also in the international realm) to capture increased government efforts to improve the rural environment.

On June 25, 2003, the Chinese government issued a *Directive to Enhance Forestry Development*, which declared that forestry should assume a leading role in the eco-construction perspective and play an important part in implementing the strategy of sustainable development (Central Committee of the Communist Party of China and China State Council 2003). The directive included a guideline for accelerating the development of forestry: strive for an eco-construction-focused pattern of sustainable development for forestry; establish an 'eco-safety' system for land in which forests and vegetation are the main foci; and protect, cultivate and rationally utilize forest resources.

The Directive also led to important accomplishments with respect to the implementation of six key forestry projects (see next section), strengthened reforms of the forest ownership policies, and contributed to the adoption of a classification system for China's forests. In this light, it has played a significant role in charting the course of development for forestry and forest management in China. With these endeavors, soil and water losses in the basins of big rivers as well as the desertification of major sand areas has been moderated, a beginning has been made at reversing the trend of overall deterioration of the China's ecological landscape, and the industrial structure of forestry has been rationalized (SFA 2008).

Actions Towards Sustainable Forestry in China

Since 1998 the Chinese government has taken a number of significant steps towards implementing SFM in China. In 2000 and 2001 the Chinese government established the 'Six Key Forestry Projects', which were envisioned as providing a framework and basis for optimizing the distribution of resources in protecting ecological resources and achieving sustainable forest management (Table 3). From 1998 to 2008, 286.58 billion RMB (US$42 billion) was invested in the six projects and 42.56 million ha of plantations were established (Table 3).

By the end of 2009, more than 101.23 million ha of forests (52.8% of the total forest area) representing all forest types were under effective protection; 9.06 million ha of cropland were converted into plantations;

8.15 million ha of sand-affected areas were controlled; and 2012 nature reserves, with a total area of 123 million ha or 12.8% of the total land area, were established. The six key projects, contributed significantly to the national economy and to the improvement of the nation's ecological health, and played an increasingly important role in promoting sustainable forestry in China.

At the end of the 1990s, China's central government also formulated a long-term forestry program called Classification-Based Forest Management (CFM), which classifies the country's forests into two categories—commercial forests (CoF) and ecological welfare forests (EWF) according to their distinct functions and services. Different policies, administrative systems and operational mechanisms are being adopted for each class. Commodity forests are managed by profit-seeking enterprises subject to market forces, with necessary support provided by the government. Ecological welfare forests are administered for the purpose of protecting valuable public assets, with direct and extensive government investment. In 2006 and 2007, the State Forestry Administration (SFA) approved about a quarter of the forestland in China as national ecological welfare forest lands on which logging is prohibited. Owners or managers of these lands receive subsidies of about 70 RMB (US$10) per hectare from the central government (Dai and others 2009).

Since the Montreal Process in 1994, in which China participated, criteria and indicators have been proposed to help better define and monitor sustainable forest management worldwide. Criteria and indicators frameworks have emerged as a powerful tool in implementing SFM internationally, with almost 150 countries now using them in their forest management and reporting processes (Wijewardana 2008). Based on the Montreal Process, China issued a set of national criteria and indicators for SFM (SFA 2002). In 2003 China, along with 11 other Montreal Process countries, developed its first 'Country Forest Reports' on SFM using 7 criteria and 67 indicators (Montreal Process Working Group 2003). After a short trial period, China also developed a set of criteria and indicators for SFM at regional levels, which cover most climate zones—temperate, cold-temperate, subtropical and tropical—and major forest biomes, including cold-temperate coniferous forest, temperate mixed coniferous and broad-leaved forest, subtropical evergreen broad-leaved forest, tropical rain forest and monsoon forest (Lei and others 2009b). To apply the criteria and indicators in practice, the state forestry administration (SFA) concurrently issued SFM guidelines (SFA (State Forestry Administration) 2006a) and an outline for compiling and implementing forest management plans (SFA (State Forestry Administration) 2006b). Both attach importance to non-timber forest resources, forest recreation, soil and water conservation, forest biodiversity, and the state of forest health in addition to conventional timber production. They are intended to provide a framework for formulating regional manuals for SFM principles and techniques, to provide forest managers with technical criteria for management, and to serve as a guide for forest management units to make science-based management plans.

Forest certification was introduced in China at the turn of the century and it quickly evolved into a potential instrument to promote SFM. After a trial period, on October 1, 2007 the state forestry administration adopted certification based on two major criteria– forest management and chain of custody (SFA (State Forestry Administration) 2007a, b). These criteria are based primarily on the content of the Program for the Endorsement of Forest Certification (PEFC) and the Forest Stewardship Council (FSC) to facilitate their integration with international standards as soon as possible. From 2001 to 2005, 439.3 thousand ha of forest in China were certified by the FSC; while by the end of 2009, to meet the growing international demand in the production of forest products, 1.2 million ha of forest were certified by FSC (SFA 2010). These fall within several forest types, ranging from tropical forests in the south to boreal forests in the north. In addition, China has developed a native certification standard system—the China Forest Certification Council—and is seeking endorsement of its standard by other programs such as PEFC and Indonesian (LEI) and Malaysian (NTCC) national schemes.

In 2004, forest tenure reform began in several provinces in south China. Elements included cuts in forest taxes, free-market mechanisms for forest asset transfers, and private support systems for forestry (Wang and others 2007). In 2008, a policy from the central government authorized the conveyance of 70-year use rights to collective forestland owners along with the right to manage their commodity forests lands for their own economic benefits (Dai and others 2009). By the end of 2009, the use rights of 100.93 million ha of collective forestland, accounting for 59.4% of the total collective forestland in the country, had been confirmed, and 48.04 million of forest tenure certificates had been received by 43.9 million families (SFA 2010). Continuing the reform of China's complex system of forest tenure is critical to the long-term implementation of its forestry projects. Use rights associated with tenure will provide farmers with a rationale to plant trees for income as well as provide incentives to protect forests (Wang and others 2007).

More recently, the Chinese government has issued an outline—the *Programming Outline for the Protection and Utilization of National Forestland(2010–2020)* [Central Committee of the Communist Party of China and China State Council 2010], which clarified the strategies, guidelines, objectives and measures to protect and utilize

forestland from 2010 to 2020. Based on this outline, by 2020 the Chinese government will strive to achieve an increase in the country's total forest area and growing stock volume of 40 million ha and 1.3 billion m^3, respectively, from levels existing in 2005.

Challenges to SFM Implementation

Although forestry in China continues to evolve, achieving the goals of SFM in China still faces many difficult challenges. We highlight five of the most important challenges below.

Environmental Degradation

The overall trend of ecological/environmental health in China, represented by improvement in some regions but deterioration in the country as a whole, has not as yet been decisively reversed. Despite substantial progress in afforestation, enhanced protection of large areas of forest lands (particularly the temperate mixed coniferous broad-leaved deciduous forest and the Larix forest in the Northeast), and some slowing of the scourge of desertification, significant problems remain. Loss of wetland areas, decreasing biodiversity, and rampant air and water pollution persist and have actually intensified over the past few decades. For example, due to excessive exploitation, large areas of subalpine *Picea* forest and Larix forest in the Xinjiang region of western China have disappeared, which has exacerbated the desertification problem in these areas. Thus the effectiveness of the actions described above in moving towards SFM in China becomes even more imperative.

Forest Productivity

A major challenge facing China is low productivity of the nation's forests. The average forest stocking volume is only 85.88 m^3/ha, which is much lower than the world average of 110 m^3/ha. The productivity of plantations is even lower at 49.01 m^3/ha. For example, the productivity of the temperate mixed coniferous broad-leaved deciduous forest in the northeast China was more than 400 m^3/ha in the 1950s, but now it is less than 200 m^3/ha. Another problem lies in the uneven age distribution of the nation's forests—67.25% of the forests are immature, which has led to a shortage in sustainable timber supply.

One important reason for the low productivity of China's forests is that the focus of China's six key forestry projects is on forest protection and afforestation, whereas improving forest quality through effective management is often neglected (Hou 2010). Under the policy of the Natural Forest Protection Program (NFPP) and the Wildlife Conservation Nature Reserves Development Program (WCNR), any logging and human activity is prohibited in some ecological welfare forests as well as any forests in nature reserve. This has led to forest degradation in some regions. For example, in Hainan Province, 667 thousand ha of tropical rain forests have been enclosed without any management since 1994. Now about 60–70% of this forest area has been destroyed by exotic invasive species—American rope (*Mikania Micrantha*) and Jinzhongteng (*Merremia boisiana (Gagn.) V. Ooststr*) (Hou and He 2010).

Tension Between Timber Supply and Demand

China's rapid economic growth, fueled in part by intensified demand for housing and a thriving export industry, has increased the consumption of lumber and other wood products.

For example, in 2009 the forest products trade in China was worth U.S.$59.66 billion (a 26.7% increase over 2006). Forest products imports were valued at $25.07 billion (a 29.5% increase over 2006) and exports at $34.59 billion (a 24.9% increase form 2006). Given the growing demand for timber driven by industrial needs in the construction, paper and furniture sectors, it is estimated that the gap between consumption and domestically produced forest products in China will be 140–150 million m^3 by 2015 (Wei and others 2009).

Increases in domestic demand, in conjunction with efforts to protect and conserve natural forests, have put more pressure on domestic timber supply. Reductions in domestic supply have in turn had effects outside of China, stimulating the import from Russia and Myanmar of logs from predominantly large, mature trees to meet this demand, often with negative ecological consequences (Mayer and others 2005; Goodman and Finn 2007). As China strives to develop a vibrant wood products industry relying primarily on domestic timber sources, in the interim it must also meet the challenge of minimizing its ecological footprint outside its boundaries with respect to timber imports.

Discontinuity Between the Concept of Eco-Construction and the Practice of SFM

There is still substantial ground to cover in replenishing forest resources depleted via excessive logging and land conversion in the latter half of the last century. Pressures abound for establishing and/or protecting both commercial (CoF) and ecological welfare forests (EWF) within the recently adopted Classification-Based Forest Management (CFM) framework for sustainable forest management.

As described earlier, in 1998 the central government passed the *Revision of the Forest Law*, in which *ecological/environmental construction* was identified as a fundamental policy objective. Its specification was, however, left extremely vague and has been interpreted basically as any activities or practices—e.g., tree planting, fencing of grassland, crop irrigation, etc.—that will improve the rural landscape. Moreover, since much of the implementation of eco-construction occurs via projects carried out by local governments, each of which interprets eco-construction from its own perspective in light of its distinctive geographical and social environments, the net effect is been that there seem to be as many interpretations of eco-construction as there are units of project-implementing local governments. Moreover, such governments, hoping to produce evidence of their success at 'greening their environments', have invariably focused on applying intensive land use practices that will yield visible, concrete results as quickly as possible. Unfortunately, this is frequently counterproductive with respect to the long-term ecological integrity of local landscapes.

Institutional and Administrative Roadblocks to SFM

The forestry sector in China has a number of structural difficulties, both for the wood products manufacturing sector and the ownership structure as a whole. For many years the state-owned forestry enterprises have served both governmental and enterprise management functions, with an individual firm's forest products plan being decided by the central government. As a result, these enterprises have been unable to compete in the market as fully autonomous competitive entities; and the administrative and operational structure of the forest products sector in China continues to struggle in adapting to volatile markets and a changing economic landscape. The wood products industry is also characterized by a small scale and a relatively limited capacity for integrating the latest contributions of science and technology within the production process.

With respect to nonindustrial private ownership segments, the land tenure system has long created a number of obstacles to sustainable forest management of collectively- and individually-owned forest lands. Within the past few years the most recent of a series of reforms offers hope that many of these will disappear, but to date the reforms in China's forest tenure system have not entirely succeeded in generating sufficient economic incentives for villagers to invest in forestry. Moreover, in some area, the compensation to owners for loss of use rights on newly-created EWF lands—also a focus of recent reform efforts—remains inadequate to outweigh their losses.

Other structural difficulties arise from the transfer of responsibilities and funding for national forestry policies and programs from the central to local governments. A key problem with local administration has been accountability with respect to the timeliness and cost-effectiveness of program delivery and accurate accounting of implementation activities. At times this has also been accompanied by misallocation of funds. Together these difficulties pose a challenge to insuring the sound degree of jurisdictional responsibility required as an essential element of effective programs for the implementation of sustainable forest management.

Strategy for SFM Implementation

The Chinese government should accord forestry a prominent position in its strategy for eco-construction, and ensure it plays an important role in the implementation of a strategy for sustainable development. A brief description of some key needed actions is provided below.

Refining the Interpretation and Strengthening the Implementation of Eco-Construction for China's Forests

There is a need for clear articulation of basic dimensions of eco-construction and the logical and practical pathways that will link the eco-construction concept and principles to SFM practices on the ground. The incorporation of basic principles of the philosophy of ecosystem management (EM) would go a long way towards rectifying the interpretive problems related to eco-construction and should become standard criteria in the design and implementation of forestry projects. Critical elements of EM include short- and long-term components of ecosystem integrity, ecological carrying capacities, conservation biology and its concern for biological diversity, the human dimension of ecological landscapes (SFA (State Forestry Administration) 2006b). Forestry programs and projects focusing on the effective control of timber harvesting in natural forests; construction of shelterbelt systems of various kinds in fragile environmental areas; protection and restoration of critical habitats for rare and endangered species; protection and restoration of natural reserves; and strengthening biodiversity via the protection of wildlife, wetlands and other critical ecosystem resources and functions, would benefit from the incorporation of these principles.

The above kinds of actions will not be feasible without increased investments in forestry eco-construction in China. There is a need to incorporate funding on a priority basis for the design and administration of the above kinds of projects as well as improvements in forestry infrastructures into the budgets of governments at all levels. It is also important to incorporate and gradually expand the

compensation funding for the provision of ecological benefits of forests into both central and local government budgets; and to expand the scale of foreign investment opportunities in China's CoF forests.

Enhancing the Momentum of Afforestation and Forest Management

Fostering a strong forest industry in China will require accelerating the development of a commercial forest base in various ways, such as via the establishment of intensive forestry operations in areas where conditions permit and focusing on rapidly-growing & productive timber species. China is in the midst of an intensive afforestation program that aims to increase forest cover (now 18.2%) to 26% by 2050 and results to date have been impressive. Thus, for example, China's State Forestry Administration reports that 28 million ha of plantations were established from 2002 to 2007 (Wang and others 2007). This momentum needs to be continued to meet the ultimate goal of ensuring a sustainable domestic supply of timber and a thriving wood products industry. An important part of this process will involve enhanced efforts to stabilize peasant land tenure structures in the hills and forests and to provide incentives for peasants to afforest barren hills and flooded lands in various ways.

A recent case showed that after ten years' forest management, the average forest stock volume of a degraded mixed coniferous broad-leaved deciduous forest in Heilongjiang Provence, northeast of China, had increased to130.8 m^3 per ha, with the net annual growth of 2.62 m^3 per ha (Hou 2010). It is estimated that if all of the 80 million ha of secondary forests in China were effectively managed, the forest stock volume of these forests would increase by 312 million m^3 per year (Hou 2010). To move in this direction, efforts to improve the quality of forest in diverse forms should be accompanied by a mass publicity campaign to encourage forest management in China. In this way, protection of ecological forests, ensuring ecosystem health and the conservation of biodiversity may also be complemented by improving the quality of commercial forests as the domestic source of timber supply.

Structural Reforms of the Forestry Sector in China

A third much-needed action involves accelerating the imposition of structural reforms in the administration of state-owned forestry enterprises by separating purely administrative governmental functions from those of enterprise management so as to enable firms to compete in the market as autonomous producing entities. This too has been recognized as problematic and the government has endorsed a policy of increased autonomy for management of CoF lands in terms of localized planning and activity selection responsive to economic and market forces rather than strict governmental controls.

A concurrent and vitally important structural reform consists of improvements in the forest land tenure system in China to clarify and safeguard the rights and interests of forest owners. The implementation of CFM has provided momentum for the government to speed up reforms in the nation's forestland tenure system. As with afforestation efforts, structural reform of China's forestry sector is another instance where a much-needed policy changes have been adopted, but major challenges remain in their effective and, particularly in the case of structural reforms, more rapid implementation.

Strengthening the Content and Effectiveness of Forestry Legislation and Regulatory Policy

Many recent policies aimed at achieving SFM emanate from foundations in key forestry laws such as the *Revision of the Forest Law* in 1998 and the subsequent *Regulations* for its implementation and *Directive* for forestry development. There remain numerous opportunities for laws and regulations in such areas as the protection of natural forests and wetlands; the administration & management of state-owned forests; the rational allocation of uses for forestland for timber and non-wood resources based on clearly defined property rights; procedures and oversight for the acquisition and use of forestry eco-construction funds; and assuring competent supervision & administration of forestry projects. This includes not only strengthening the formulation of new laws but also mechanisms for assessing the effectiveness of existing laws and regulations and their revision, if necessary, in light of new conditions. Among the above, virtually all observers of the course of the evolution of forestry and forest management in China agree with Wang and others (2007) that continued reforming of China's complex system of forest ownership and user rights—including their ultimate grounding in the solid foundation of law—is critical to the long-term implementation of its forestry programs.

Promoting Sustainable Forestry Practices in China Through Effective Education and Application of Science and Technology

Finally, it is essential to attach continuing importance to the basic study and application of forestry science as well as the development and use of new technologies in the fields of forestry and environmental management. This includes focusing research efforts on the development of such key technologies as high-quality seed selection & cultivation, forestation in ecologically sensitive and/or

degraded areas, prevention & control of serious plant diseases and insect pests, prevention and control of desertification, and the prevention and suppression of forest fires. While continued support for forestry-related educational and research programs in academic institutions is warranted, it is also crucial to establish various kinds of educational programs for forest administrators and managers and intensify the training of forestry employees throughout the country.

Although China's forests and ecological landscape suffered extensively during the last century, it appears that the corner has been turned as the vision of sustainable forest management becomes more assimilated into forest legislation and policy. But the task of putting that vision into practice remains a daunting one. Meeting the challenges outlined above is essential if China is to assume its part of the responsibility shared by all nations of fostering ecological health both for their own citizens and as a member of the world community.

Acknowledgments This research was financially supported by the National Natural Science Foundation of China (40873067 &30800139); the International Partnership Program for Innovation Team and the Visiting Professorship Program for Senior International Scientists of the Chinese Academy of Sciences; and the National Forestry Public Welfare Program of China (201104070).

References

Bystriakova N, Kapos V, Lysenko I, Stapleton CMA (2003) Distribution and conservation status of forest bamboo biodiversity in the Asia-Pacific Region. Biodiversity and Conservation 12:1833–1841

Central Committee of the Communist Party of China and China State Council (2003) Directive to enhance forestry development. http://news.xinhuanet.com/zhengfu/2003-09/11/content_1075042.htm. Accessed online 11 Sept 2003 (in Chinese)

Central Committee of the Communist Party of China and China State Council (2010) The programming outline for the protection and utilization of national forestland (2010–2020). Central Committee of the Communist Party of China and China State Council, Beijing (in Chinese)

Central Government of PR China (1985) Forest law of the Peoples Republic of China. Central Government of PR China, Beijing (in Chinese)

Central Government of PR China (1998) Forest law of the Peoples Republic of China (Revision). Central Government of PR China, Beijing (in Chinese)

Chen LZ, Chen QL, Liu WH (1997) Forest diversity and its geographical distribution in China. Geology Publishing House, Beijing (in Chinese)

China Vegetation Atlas Editorial Committee of the Chinese Academy of Science (2001) Atlas China vegetation. Science Publishing House, Beijing (in Chinese)

Committee for Natural Regionalization of the Chinese Academy of Science (1959) Climatic regionalization of China. Science Publishing House, Beijing (in Chinese)

Dai LM, Zhao FQ, Shao GF, Zhou L, Tang LN (2009) China's classification-based forest management: procedures, problems, and prospects. Environmental Management 43:1162–1173

Editorial Committee for Vegetation of China (1980) Vegetation of China. Science Publishing House, Beijing (in Chinese)

Editorial Committee for Vegetation of China (2007) Vegetation and its geographical distribution in China—illustration of the vegetation map of China (1: 1000, 000). Geological Publishing House, Beijing (in Chinese)

Goodman P, Finn P (2007) Corruption stains timber trade. http://www.washingtonpost.com/wp-dyn/content/article/2007/03/31/AR2007033101287.html. Accessed 1 April 2007

Hou YZ (2010) Forest can enrich the country, but need policy. http://www.eco-services.ac.cn/ClassView.asp?flag=1&id=208 (in Chinese)

Hou YZ, He Y (2010) Reflection of the natural forest protection policy. http://www.eco-services.ac.cn/ClassView.asp?flag=1&id=216 (in Chinese)

Lei JP, Jiang ZP, Xiao WF, Huang XR (2009a) Research on criteria and indicators for sustainable forest management at regional level in China. Journal of Northwest Forestry University 24:228–233 (in Chinese)

Lei XD, Tang MP, Lu YC, Hong LX, Tian DL (2009b) Forest inventory in China: status and challenges. International Forestry Review 11:52–63

Li WH (2004) Degradation and restoration of forest ecosystems in China. Forest Ecology and Management 201:33–41

Liang TR (1990) Types and geographical flora characteristics of bamboo forest in China. Journal of bamboo research 9:1–16 (in Chinese)

Mayer AL, Kauppi PE, Angelstam PK, Zhang Y, Tikka PM (2005) Importing timber, exporting ecological impact. Science 308: 359–360

Montreal Process Working Group (2003) Montreal process first forest overview report. Montreal Process Working Group, Montreal

Ni J, Zhang XS, Scurlock JMO (2001) Synthesis and analysis of biomass and net primary productivity on Chinese forests. Annals of Forest Science 58:351–384

Richardson SD (1990) Forests and forestry in China—changing patterns of resource development. Island Press, Washington DC

SFA (State Forestry Administration) (1997) China's forestry yearbook. China's Forestry Publishing House, Beijing (in Chinese)

SFA (State Forestry Administration) (2002) China issued the national level criteria and indicators of sustainable forest management in China. SFA, Beijing (in Chinese)

SFA (State Forestry Administration) (2006a) Guideline on sustainable forest management. SFA, Beijing (in Chinese)

SFA (State Forestry Administration) (2006b) Outline on making forest management plan. SFA, Beijing (in Chinese)

SFA (State Forestry Administration) (2007a) Forest certification in China—forest management. SFA, Beijing (in Chinese)

SFA (State Forestry Administration) (2007b) Forest certification in China—chain of custody SFA, Beijing (in Chinese)

SFA (State Forestry Administration) (2008) China forestry development report 2007. Forestry Publishing House, Beijing (in Chinese)

SFA (State Forestry Administration) (2009) The 7th national forest inventory. SFA, Beijing (in Chinese)

SFA (State Forestry Administration) (2010) Condition of forest certification in the world. http://www.forestry.gov.cn/portal/main/s/241/content-443812.html (in Chinese)

United Nations Food and Agriculture Organization (FAO) (2010) Global forest resources assessment 2010. FAO Forestry Paper

Wang S, van Kooten GC, Wilson B (2004) Mosaic of reform: forest policy in post-1978 China. Forest Policy and Economics 6:71–83

Wang GY, Innes JL, Lei JF, Dai SY, Wu SW (2007) China's forestry reforms. Science 318:1556–1557

Wei Y, Lu WM, Lang SP (2009) An analysis of main influencing factors for timber import of China. World Forestry Research 2:78–80

Wijewardana D (2008) Criteria and indicators for sustainable forest management The road travelled and the way ahead. Ecological indicators 8:115–122

Xiao XM, Boles S, Liu JY, Zhuang DF, Liu ML (2002) Characterization of forest types in Northeastern China, using multi-temporal SPOT-4 VEGETATION sensor data. Remote Sensing of Environment 82:335–348

Zhang YX (2008) Forest management conditions and problems from 1950 to 2003 in China. Journal of Beijing Forestry University 30:91–96 (in Chinese)

Zhang PC, Shao GF, Zhao G, Le Master DC, Parker GR, Dunning JB Jr, Li QL (2000) China's forest policy for the 21st century. Science 288:2135–2136